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**HYDROCHEMICAL ASPECTS OF LAKES AND
CHANNELS IN THE MACKENZIE DELTA, N.W.T.**

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MANAGEMENT PERSPECTIVE

This study was conducted as part of the "Mackenzie Delta Lake Regimes Study" which sought to identify potential environmental impacts, river flow regulation of the Mackenzie River could have on the hydrologic regime of lakes in the Mackenzie Delta. Research conducted on the hydrologic regime of these lakes has shown that they receive very little recharge from surface runoff and precipitation, and depend on spring flooding for replenishment. This study sought to determine if these lakes also depended on spring flood waters for chemical recharge.

As part of the federal government's commitment to the "Management of Northern Water Resources", the information presented in this report is essential to develop an understanding of the natural and anthropogenic changes which may be occurring in the chemical composition of water in the Mackenzie Delta lakes. Further research of this nature will help prevent some of the serious ecological changes which often accompany socio-economic development in the North.

PERSPECTIVE DE GESTION

La présente étude a été menée dans le cadre de "L'étude du régime des lacs du delta du Mackenzie" qui visait à identifier les incidences écologiques éventuelle de la régularisation du débit du fleuve du Mackenzie sur le régime hydrologique des lacs du delta du Mackenzie. Les recherches sur le régime hydrologique de ces lacs ont montré qu'ils ne sont que très peu alimentés par le ruissellement et les précipitations et que leur réapprovisionnement annuelle dépend de la crue printanière. L'étude visait à déterminer si les paramètres chimiques de ces lacs dépendent également des eaux apportées par la crue printanière.

Dans le cadre de l'engagement du gouvernement en matière de "gestion des ressources en eau dans le Nord", les renseignements présentés dans ce rapport sont essentiels à la compréhension des modifications naturelles et anthropogènes que peut subir la composition chimique de l'eau des lacs du delta du Mackenzie. Des recherches plus approfondies de même nature aideront à prévenir les sérieuses modifications écologiques qui accompagnent souvent le développement socio-économique dans le Nord.

ABSTRACT

The analysis of over 200 snow, ice core and water samples collected prior to break-up, and at peak and low stage periods during the 1982 and 1983 field seasons from thirty lake and channel sites throughout the Mackenzie Delta, N.W.T., were used to ascertain if and how the hydrological processes controlling lake and channel water levels effect the water quality characteristics of Delta lakes and channels. The water quality parameters chosen for analysis were; water temperature, conductivity, pH, turbidity and ionic concentrations of calcium and magnesium.

The results of this study underline the importance of spring break-up and flooding to the chemical composition of Delta lake and channel waters. Without the replenishment of minerals which occurs during the flooding of lakes and channels in the spring, it is likely that the Delta could not sustain its present plant and animal populations. Lake and channel water quality characteristics showed strong seasonal fluctuations coinciding with seasonal variations in the water level. Spatial patterns in water quality characteristics, however, were not as easily detected. The geomorphology of the Delta has an affect on the spatial variation of lake and channel water chemistry, but its importance to the overall chemical composition of lake and channel waters was not clear. In order to achieve a more complete understanding of the natural and anthropogenic changes occurring in the chemical composition of Delta lake and channel waters, an intensive water quality monitoring program will have to be implemented in the Mackenzie Delta.

RESUME

Des analyses de plus de 200 échantillons de neige, de carottes de glace et d'eau recueillis avant la débâcle ainsi qu'en périodes de débit de pointe et d'étiage pendant les saisons de travaux sur le terrain de 1982 et 1983 dans trente lacs et chenaux répartis dans tout le delta du Mackenzie (T. N.-O.) ont été utilisées pour vérifier si et comment, le cas échéant, les processus hydrologique régissant les niveaux de l'eau influencent les caractéristiques de la qualité de l'eau dans ces lacs et chenaux du delta. Les paramètres de la qualité de l'eau retenus pour les analyses étaient la température, la conductivité, le pH, la turbidité et les concentrations ioniques de magnésium et de calcium.

Les résultats de la présente étude soulignent l'importance de la débâcle et de la crue printanière pour la composition chimique des eaux des lacs et chenaux du delta. Sans le réapprovisionnement en minéraux assuré par l'inondation des lacs et chenaux au printemps, il est vraisemblable que le delta ne pourrait plus supporter les actuelles populations de plantes et d'animaux. Les caractéristiques de la qualité de l'eau des lacs et chenaux présentent de fortes fluctuations saisonnières qui coïncident avec les variations saisonnières du niveau de l'eau. Les configurations spatiales des caractéristiques de la qualité des eaux n'étaient toutefois pas aussi faciles à détecter. La géomorphologie du delta exerce une influence sur la variation spatiale de la chimie de l'eau des lacs et chenaux, mais son importance pour la composition chimique générale de ces eaux n'est pas claire. Afin de mieux comprendre les modifications naturelles et anthropogènes de la composition chimique des eaux des lacs et chenaux du delta, un programme intensif de surveillance de la qualité de l'eau devra être mis en oeuvre dans le delta du Mackenzie.

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HYDROCHEMICAL ASPECTS OF LAKES AND CHANNELS IN THE MACKENZIE DELTA, N.W.T.

1.0 INTRODUCTION

The Mackenzie River is the longest river in Canada extending over 4,200 km from the Finley River headwaters in British Columbia to its mouth at the Beaufort Sea (Figure 1). The Mackenzie River basin drains some 1,787,000 km², or nearly one-fifth of mainland Canada. The basin drains vast areas of muskeg and tundra, as well as areas with varied soil types and bedrock.

The water quality analysis and interpretative work conducted by Thomas (1957), Levinson, et al. (1969), Hitchon, et al. (1969), Reeder, et al. (1972), Reeder (1973) on the Mackenzie River drainage basin showed that these waters were virtually unpolluted at the time of sampling. Consequently the water chemistry directly reflects the regional physiography.

In recent years, the Mackenzie River basin has been undergoing extensive natural resource development. A series of northern mega-projects including hydroelectric installations, pipeline construction, and facilities for exploration and extraction of hydrocarbons are underway. Our knowledge of the natural and anthropogenic changes which may be occurring in the water quality of the Mackenzie River and Delta has not kept pace with these developments (Mackenzie River Basin Committee, 1985).



Figure 1: Mackenzie River basin and subbasins

The Mackenzie Delta is known for its abundant plant, fish, waterfowl and wildlife (Mackenzie River Basin Committee, 1981a). The Delta has distinct plant and animal communities, as a result of a complex web of climatic, fluvial and biological processes interacting. These processes involve the intricate relationships of depositional and erosional forces, vegetational response to these processes, and vegetational control over wildlife habitat selection, all combining to allow a variety of flora and fauna to flourish in a flood prone delta. However, because it is an Arctic delta besieged by harsh climatic conditions and a short summer season (approximately 3 months), a delicate balance exists between the populations and their habitat. Any changes in the flow regime or water quality could have a detrimental effect on this northern ecosystem (Gill, 1971; Mackenzie River Basin Committee, 1981b).

Hem (1970) described many of the environmental factors to which water may be exposed to in the hydrologic cycle, as well as the various techniques available for water quality analysis. Several of the water quality parameters he suggested for analysis provide reliable spatial and temporal data on the chemical composition of water. As well, water quality characteristics in conjunction with responsible interpretation are often used to determine the water source, its relationship with the surrounding watershed, modifications which have occurred as a result of contact with foreign materials, and biologically or industrially induced changes.

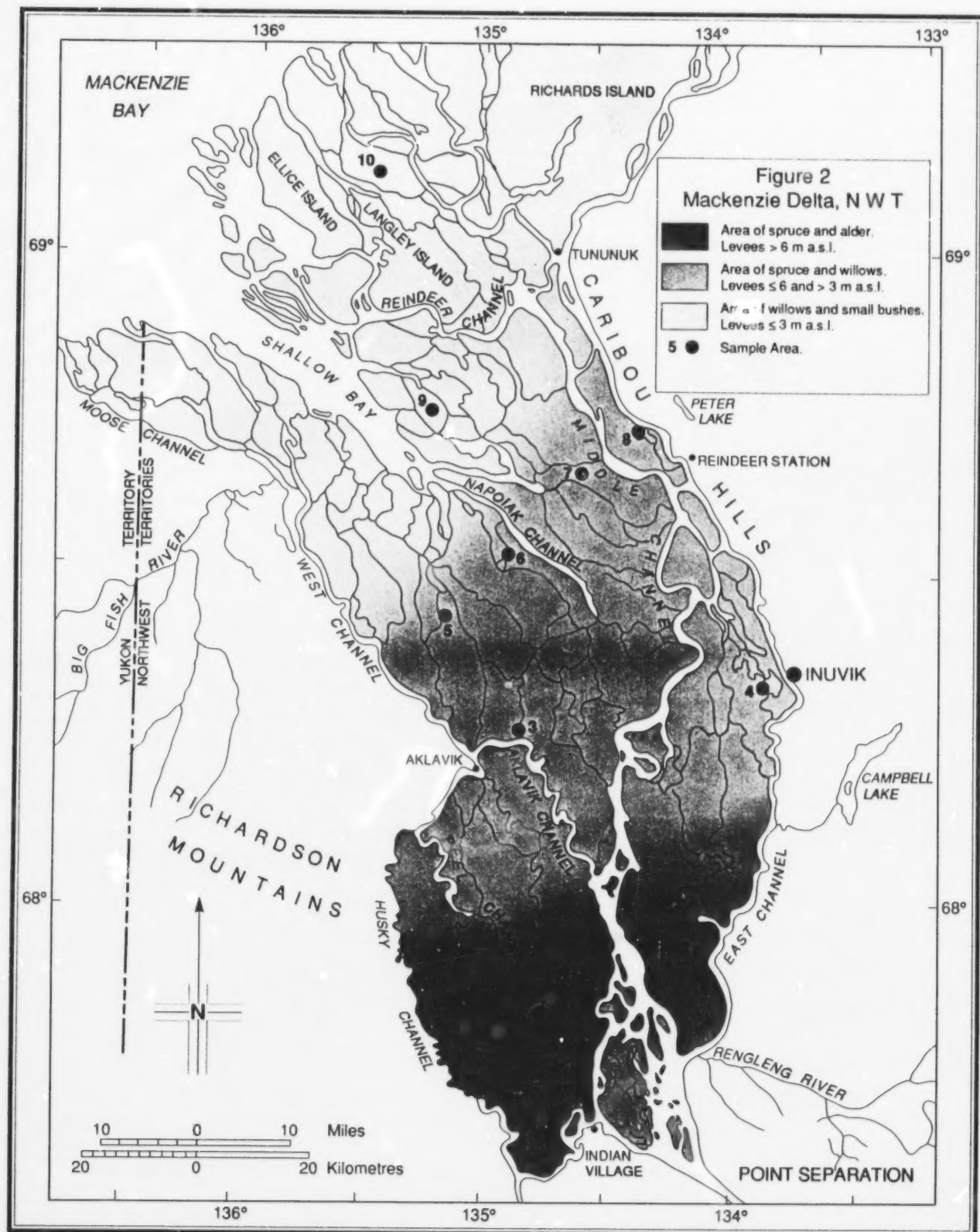
In 1982 and 1983, the analysis and interpretation of the chemical characteristics of water obtained from a spatial and temporal series of water samples were used to document pre-break-up, peak stage and low stage conditions as they relate to the water quality of thirty lake and channel sites located in

ten study areas throughout the Mackenzie Delta (Figure 2). Specifically, this report intends to: a) provide baseline information on physical parameters and major ion content of channel and lake water in the Delta; b) assess the effect and importance of spring flooding on the water quality of Delta lakes and channels; c) identify spatial and temporal trends in the water quality of lakes and channels located in the various regions of the Delta; d) identify any spatial differences between lake and channel sites within the same study area.

2.0 STUDY AREA, MACKENZIE DELTA N.W.T.

The Mackenzie Delta covers an area of approximately 12,000 km² comprised of a maze of channels and shallow lakes. The Richardson Mountains to the west and the Caribou Hills on the east sharply delineate the Delta (Figure 2). It is an active delta that continues to extend into the Beaufort Sea. The Delta has a very gentle slope varying only a few metres (2 to 3) over approximately 200 km. It has numerous lakes, ponds and channels but also contains land ranging from stable forested areas in the south to tidal flats at the northern end. Permafrost underlies most of the Delta land mass.

During the summer months, the active layer can extend a metre or more into the soil. Active layer depth increases inversely with elevation above water level (i.e. from the levee top down towards the channel water). The lakes and channels are underlain by large talik zones, extending many metres in depth (Johnston and Brown, 1964).



There are three distinct regions according to levee height (Mackay, 1963) and vegetation type (Gill, 1978) (Figure 2), with a diversity of lakes. These lakes fall roughly into five broad genetic types: abandoned channel lakes, point bar lakes, floodplain lakes, thermokarst lakes, and dammed lakes (Mackay, 1963). Subsequent studies dealing with the hydrological regimes of lakes and channels (Bigras, 1986) have categorized lakes according to their morphological characteristics. Connected lakes have a well-defined, water-filled channel connecting them to the main Delta channel system during the open water season. These lakes are constantly interchanging water with Delta channels, and the lake level is similar to that of the distributary channel throughout the open water period. Connected lakes are located throughout the Delta and have an average depth of 1.30 m in mid-summer (Bigras, 1987).

Most lakes not directly connected by a channel in the Delta are perched atop levees and are cut off from other lakes and channels for most of the year. These perched lakes have an average mid summer depth of 1.0 m (Bigras, 1987). Perched lakes can be divided into three groups. In the northern and central Delta, most perched lakes usually have a small depression in the levee hidden by overgrowth, linking them to other lake systems. These lakes are known as lakes with closures (Mackay, 1963). They can have either a high- or low-closure connecting them intermittently to other lakes or channels during the brief spring flood or occasionally during high water. When water levels increase sufficiently, 2.0 meters a.s.l. or less for low-closure lakes, and 2.0 or more metres a.s.l. for high-closure lakes infilling commences (Bigras, 1985). The third group consists of unconnected lakes which are elevated high above the Delta channel system, have no depression in the levee linking them to another lake system, and are not flooded annually. These lakes are located

exclusively in the southern portion of the Delta and tend to have a negative annual water balance. Without spring flooding to replenish annual water loss, these lakes would dry up (Marsh and Bigras, 1988).

Ten representative study areas were chosen from the three Delta regions (Figure 2). Each area was to include a pair of lakes, one having a direct low water connection to an active Delta channel, the other having no connection (i.e. closure or perched lake) except possibly under spring flood conditions or an exceptional hydroclimatic event. Lakes should not be threatened by "tapping" (i.e. catastrophic drainage) due to Delta channel bank erosion for at least the foreseeable future.

Areas 1 and 2 are situated in the southern portion of the Delta, a region where shallow lakes cover approximately 20% (*) of the area.

Areas 3 and 4 are located in the south-central Delta, where lakes occupy about 40% of the region. Study areas 5 through 8 are in the north-central portion of the Delta, but lakes in this region occupy approximately 50% of the landmass.

(*) NOTE: Percentage figures for lakes occupying an area were obtained through air photo analysis. Three swaths approximately 10 km wide and extending across the southern, central and northern Delta were overflown a minimum of three times each, as part of the Delta break-up study. Lake, channel and landmass areas within each swath were measured using a digital planimeter.

Study areas 9 and 10 are located in the northern Delta where the area occupied by lakes varies depending on the time of the year and the water level. In mid-summer lakes usually occupy 25% of the region.

3.0 WATER QUALITY ANALYSIS

3.1 METHODOLOGY

3.1a Water quality parameters and instrumentation

The water quality characteristics discussed in this report are water temperature, specific conductance, pH, turbidity, and major ions (calcium and magnesium). These physical and chemical water quality parameters are essential to the survival and propagation of aquatic vegetation and animal life, as well as being good indicators of spatial and temporal variations in the chemical composition of water.

Water temperature is an important physical parameter of water in that it affects physical, biological and chemical processes in the aquatic environment. Variations in temperature usually follow the climatic regime of the area, and exhibit strong seasonal and diurnal variations. Conductivity provides a good indication as to the changes in water composition with respect to ionic concentration, which will increase as more dissolved solids enter the system. The hydrogen ion concentration or pH depends on the extent of hydrolysis of anions and cations in natural water. In turn, the pH value can reflect the solvent power of water thereby giving some indication as to its possible reactions on rocks and soils (Hem, 1970), and can have a detrimental effect on plant and animal life if it is too acidic. The amount of solid materials in

suspension in the Delta lakes and channels exhibits strong temporal variations. This in turn causes significant variations in turbidity values, especially during spring break-up and flooding. Turbidity is a good indicator of the amount of suspended material entering Delta lakes and channels. Suspended materials can greatly affect photosynthesis which in turn will affect aquatic biological communities. Calcium and magnesium are abundant cations and are readily soluble in water. They are also essential nutrients required to sustain plant and animal life.

A LaMotte multirange conductivity meter with a manual temperature compensation from 0°C to 100°C was used for measuring conductivity. Stated accuracy is $\pm 2\%$ full-scale reading, with a precision of $\pm 0.5\%$ full scale reading. The probe constant was 5.0/cm.

A LaMotte pH meter with a manual temperature compensation which regulates temperature readings within a 0°C to 100°C range was used. Stated accuracy is ± 0.1 pH unit, with a precision of ± 0.05 pH unit.

Turbidity was measured using the absorptometric method and a colorimeter, which had a sensitivity of 5 Formazin Turbidity Units (FTU).

Total hardness and calcium concentrations were determined using the Titrimetric EDTA (sodium ethylene-diamine tetraacetate) method, with a sensitivity of 4.0 mg/L and 4.0 mg/L respectively. Since the total hardness of water generally represents the total concentration of calcium and magnesium ions expressed as calcium carbonate, the magnesium concentration was then obtained by the subtraction of calcium from the total hardness.

Conductivity and pH meters were calibrated prior to the analysis of each water sample. The colorimeter was also calibrated prior to each analysis.

Water temperatures were recorded on a Peabody Ryan model "J" thermograph. It is capable of recording continuously for up to six months, and is accurate to 0.6°C. This thermograph was used at lake and channel sites in areas 2, 4 and 8.

3.1b Sampling framework and procedures

An ideal study of the water quality characteristics of Delta lakes and channels would have extended throughout the entire open water period. But due to budgetary and man-power constraints, it was decided to concentrate on three important periods in the hydrologic regime of the Mackenzie Delta. The sampling procedures used in this study and outlined in the following sections are described in detail in Sampling for Water Quality (Environment Canada, 1983b).

Mid April to early May

The pre break-up period was selected in order to determine the effect spring flooding has on the water quality characteristics of the lakes and channels. In this manner, the chemical composition of water from lake and channel study sites was assessed prior to flooding. However, this early in spring lakes and channels are still frozen to their bed. As a result, an ice core sample was collected at each one of the thirty lake and channel sites. This was the only means that assured a uniform testing medium. Ice core length varied a great deal, but the white ice to black ice ratio of 1:2 was fairly consistent. Snow samples were taken from areas 8, 4 and 2 (Figure 2), in order to ascertain the chemical loading potential of snow.

Ice cores were extracted using a teflon-coated SIPRE corer, and stored in polyethylene bags. Prior to analysis, ice cores were removed from the polyethylene bag and left to melt at room temperature in 5-liter glass beakers, which had been washed in a mild solution of hydrochloric acid (HCl - 1 Normal), rinsed several times with deionized water, and covered with polyethylene. Snow samples were collected in polyethylene bags, and left to melt at room temperature in 5-liter glass beakers suitably washed and covered with polyethylene.

Late May to early June

The peak water level in the Delta coincides with the spring break-up and flood. Water samples were collected as close to peak stage as possible, weather and ice conditions permitting. In this manner the chemical composition of lake and channel waters at the time of flooding can be determined.

At lake sites, water samples were collected from the middle of the lake. Water samples from channel sites were taken at the centroid of flow. Each discrete grab sample was collected on the outer perimeter of the helicopter floats in a Van Dorn bottle and was transferred to a 1000 ml polyethylene bottle, previously rinsed in the laboratory with weak hydrochloric acid (HCl - 1 Normal), and then rinsed several times with deionized water before using them in the field. All samples were filtered using individual Watman 42 Ashless filter paper and analyzed within twenty-four hours.

Late August to early September

Water samples were collected once more during the low stage period at each of the study sites. Chemical concentrations at the end of the open water season are expected to be low due to chemical uptake by plants and animals, as well as through adsorption. These samples will complete the series required to detect temporal and spatial variations in the water quality characteristics of lakes and channels which occurred during the course of the open water period.

The same sampling procedures as outlined in the preceding section were followed during the September survey of the ten study Areas (Figure 2). Occasionally, there are gaps in the water quality data for some of the sites as a result of unfavorable sampling conditions.

3.2 HYDROLOGIC REGIME OF LAKES AND CHANNELS

The mean date for complete freeze over of East Channel at the town site of Inuvik is October 11 (Allen, 1977). At this time and on into winter, channel water levels can drop a meter or more below the autumn low-water level, causing the ice cover to sag and hinge cracks to appear. This effectively isolates distributary channels in the southern portion of the Delta from the flow in main Delta channels. In the spring when shoreleads develop and water levels rise in the main channels, the height difference incurred over the winter, exhibited by the sagging ice cover, must be matched before an increase in the distributary channel water level will occur. On the other hand, channels and connected lakes in the central and northern Delta are not as elevated, and are cut off from the main Delta channels because they are frozen solid, or have an

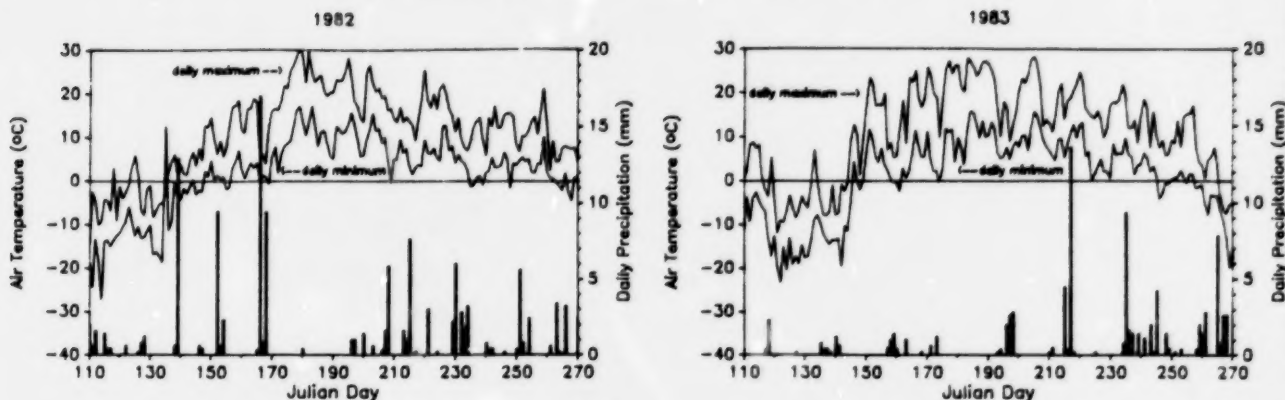
elevated lake closure. The winter accumulation of ice reaches its maximum thickness late in April. The average ice thickness at this time for distributary channels is 60 cm, while connected lakes average 52 cm and perched/closure-type lakes have an average thickness of 57 cm.

The transition from winter to spring is abrupt in the Delta region. Early in May, the cold Pacific highs which dominate the Delta during the winter months are broken down by a series of intruding weather systems which bring increased radiation and warmer air temperature. An increase of approximately 9.0°C in the mean monthly air temperature is recorded between both April-May and May-June (Figure 3a; Environment Canada, 1983a, 1982). Snow-melt run-off from surrounding lake basins contributes very little to the increase in lake water volume. In fact, research on Delta lake hydrology has shown that only 13% of the total snowmelt runoff reaches the lakes in the spring (Bigras, 1986, 1987).

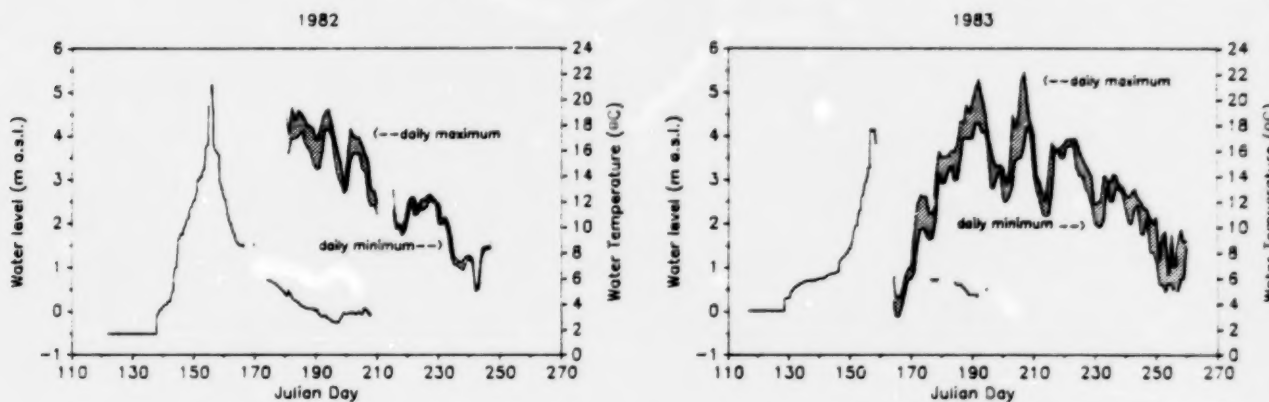
Break-up in the southern portion of the Mackenzie basin (Mackenzie River at the confluence of the Liard River) commences, on average by May 11 (MacKay 1965). By the time these meltwaters reach the Mackenzie Delta they have travelled some 1500 kilometers, and are laden with sediment and are much warmer than the Delta waters (Terroux et al., 1981; Bigras, 1988).

In the spring of 1982 break-up was mechanical, and the controlling effect of ice jams on water levels in the Delta was demonstrated. Mechanical break-ups are characterized by the dynamic movement of the ice front downstream. Air temperatures are low, and because much of the winter snow pack remains on the ice surface, albedo is high. When these conditions persist during break-up, the ice cover remains competent and break-up depends on the arrival of a high

(a) METEOROLOGICAL OBSERVATIONS, INUVIK AIRPORT



(b) DISTRIBUTARY CHANNEL HYDROGRAPH AND WATER TEMPERATURE, AREA 8 *



(c) PERCHED LAKE HYDROGRAPH AND WATER TEMPERATURE, AREA 2

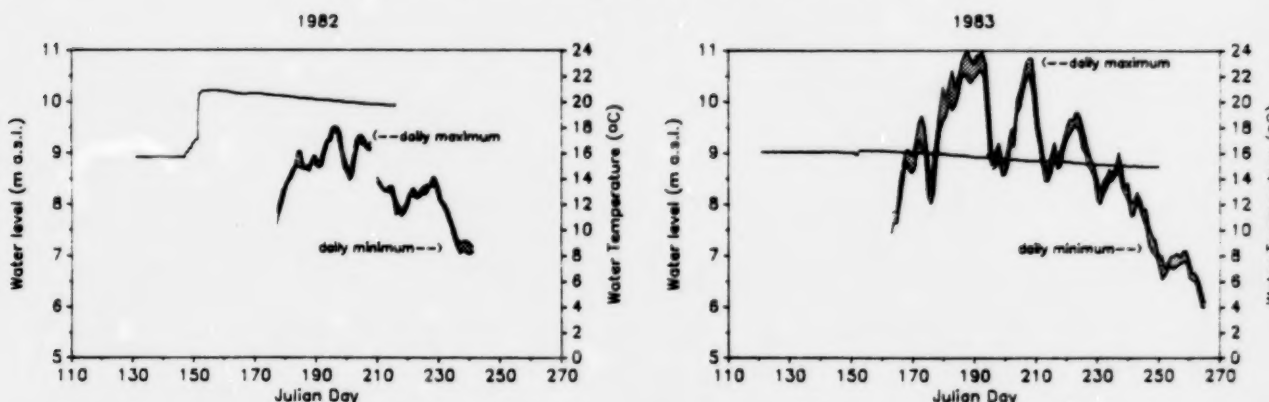


Figure 3: Hydrometeorological Observations, Mackenzie Delta, N.W.T.

* In 1983, an inertial survey of the Mackenzie Delta was conducted so that water level monitoring sites could be linked to a common datum reference. Throughout the survey, -0.81 meters was used as the mean sea level reference. As a result most sites in the northern Delta have negative water level readings from time to time.

magnitude, high velocity flood wave.

In 1982 the advancing ice front encountered a competent ice cover on Middle Channel, where it jammed and remained static for several days, causing record high water levels upstream (Table 1) and flooding of the southern Delta region (Bigras, 1985).

During the spring of 1983, break-up was thermal. This kind of break-up is characterized by extensive melting of the ice cover and irregular progression of the ice front downstream. In general, conditions which prevail during a thermal break-up include warm air temperatures, high solar insolation, reduced albedo, low water flow, and an extremely weakened ice cover. According to this description the 1983 break-up was a typical thermal break-up year. An ice jam did form on Middle Channel, but it did not remain long enough to cause flooding of the southern Delta. Flooding did occur in the central and northern regions (Table 1).

Spring flooding is the main event in the annual hydrologic regime of Delta lakes and channels. At this time, maximum water levels are recorded as a result of the flooding (Figure 3b, and 3c). Once the peak water level has been attained, the water level at lake and channel sites drops rapidly. Connected lakes in the southern Delta will empty into their respective distributary channels until they reach their closure level, cutting off the surface flow. Connected lakes in the central and northern Delta continuously exchange water with distributary channels throughout the open water season.

After the spring flood, perched lakes with closures empty into adjoining lake systems until the water level reaches the closure level and the flow ceases. For the remainder of the open water season these lakes are cut off from the main Delta channel unless an extreme hydrometeorological event occurs (i.e. extreme precipitation event upstream; storm surge along the Beaufort coast). Unconnected lakes are flooded only in the spring when exceptional circumstances occur, as was the case during spring break-up in 1982 (Figure 3c). Most perched lakes have a negative annual water balance. Snowmelt and annual precipitation are not sufficient to sustain perched lake levels (Marsh and Bigras, 1988), unless flooded on a regular basis they are destined to dry up (Figure 3c).

The difference in elevation from south to north in the Delta plays an important role in the hydrologic regime of Delta lakes and channels. Levee heights decline from about 10 m a.s.l. in the southern Delta to less than 2 m a.s.l. in the northern Delta (Figure 2). Lake closure height (i.e. low-, high-closure), or the elevation at which lakes are perched atop Delta levees affects the flooding sequence, and in the case of perched lakes whether or not these lakes will be flooded at all. Consequently, Delta geomorphology determines the extent of flooding in each region. The area flooded increases as levee height decreases. The northern and outer portion of the central Delta are flooded annually. Only in exceptional circumstances, such as those encountered in 1982 is the southern region of the Delta flooded (Bigras, 1985).

3.3 WATER QUALITY RESULTS and DISCUSSION

3.3a WATER TEMPERATURE

An indication of increasing water temperatures in lakes and channels is the development of shoreleads early in the spring. Snow-melt ponds on the ice surface, while snow-melt run-off from the surrounding land mass causes shoreleads to develop between the ice cover and lake and channel banks which weaken and finally free the shore-fast ice sheet. By this time warm water from the Mackenzie River enters the Delta channel system and melts the ice cover from underneath, contributing to a further decrease in the structural strength of the ice cover. By late June, the ice cover on the Delta lakes has completely melted.

The continuous exchange of water between distributary channels and main Delta channels during the open water season affects the daily water temperature of the smaller and shallower distributary channels. The average monthly water temperature(*) for channels during the open water period were 13.8°C for June, 16.4°C for July and 13.1°C for August. Channel water temperatures responded quickly to diurnal fluctuations in air and water temperatures, with a difference between the daily maximum and minimum water temperatures reaching as high as 4°C (Figure 3b).

(*) Water temperature data were collected at lake and channel study sites in Areas 2, 4, and 8. The average monthly temperature was then calculated for homogeneous sites over the two year study period.

Since connected lakes in the Delta are relatively shallow (average mid-summer depth of ≤ 2.0 metres), there was no perceivable temperature stratification. The average monthly water temperature for June was 13.8°C, 16.0°C for July, and 11.4°C for August. The average difference between daily maximum and minimum temperatures over the three month period for connected lakes was 2°C. In general, diurnal fluctuations in lake water temperatures tended to parallel those of their distributary channel, although their response to the daily variations in air and water temperatures lagged a few hours behind those recorded at their respective distributary channel sites.

Perched lakes are also quite shallow (average mid-summer depth of ≤ 1.0 metre), and during the summer water levels in the surrounding lakes and channel are not high enough to link them to the main Delta channel system. As a result, perched lakes are usually not affected by the continuous exchange of water with Delta channels during the summer months. The average monthly water temperatures for June, July and August were 14.2°C, 17.1°C and 12.9°C respectively. Daily water temperatures for these lakes were generally higher than those recorded at the other lake sites (Figure 3c). Because there is very little circulation within these lakes, diurnal fluctuations in water temperature were minimal (Figure 3c). There was a lag time of several hours before these lakes responded to diurnal variations in the air temperature.

3.3b CONDUCTIVITY

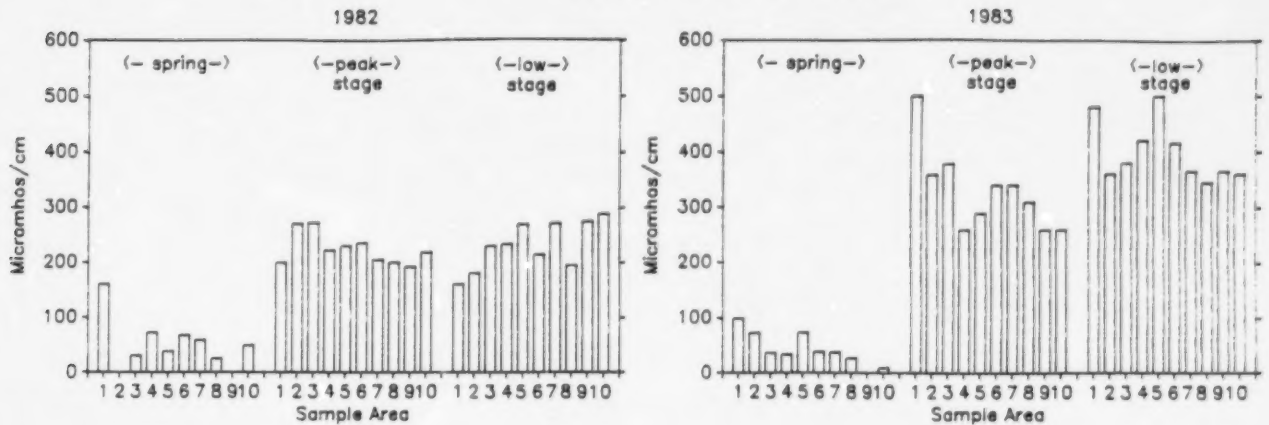
During the two study seasons (spring-summer of 1982 and 1983), conductivity values for distributary channels ranged from 9 $\mu\text{S}/\text{cm}$ to 500 $\mu\text{S}/\text{cm}$. Ice core samples from distributary channels had an average conductivity value of 52 $\mu\text{S}/\text{cm}$. With the advent of spring flooding, a sudden surge in the conductivity levels occurred, with conductivity averaging 277 $\mu\text{S}/\text{cm}$. Low water levels late in the summer saw a further increase in conductivity readings, and an average of 316 $\mu\text{S}/\text{cm}$ (Figure 4).

Conductivity levels for connected lakes ranged from 9 $\mu\text{S}/\text{cm}$ to 660 $\mu\text{S}/\text{cm}$. Spring and peak water level conductivity values for these lakes were similar to those of their respective distributary channels (Figure 4), with an average value of 65 $\mu\text{S}/\text{cm}$. Spring flooding resulted in a pronounced increase in conductivity, with an average reading of 257 $\mu\text{S}/\text{cm}$. By late summer water levels were much lower, and conductivity levels had increased to an average value of 320 $\mu\text{S}/\text{cm}$.

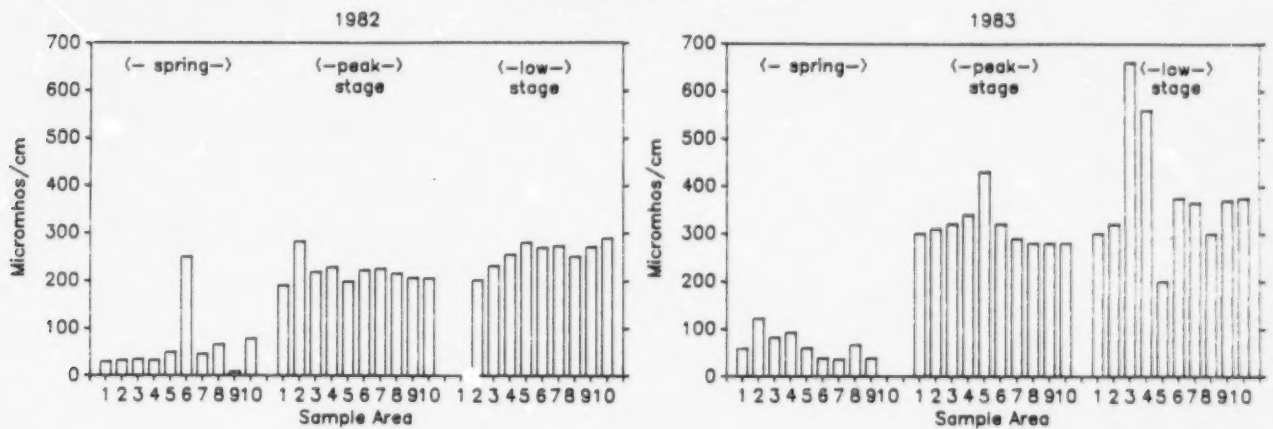
Conductivity values for perched lakes ranged from 8 $\mu\text{S}/\text{cm}$ to 440 $\mu\text{S}/\text{cm}$. These lakes had a combined spring average of 86 $\mu\text{S}/\text{cm}$. At the height of spring flooding the average was 238 $\mu\text{S}/\text{cm}$. With the arrival of fall and lower water levels the average conductivity reading rose to 277 $\mu\text{S}/\text{cm}$ (Figure 4).

Conductivity is normally a good indicator of spatial and temporal changes in water composition as a result of variations in the amount of dissolved solids. This was not the case for Delta lake and channel study sites. Conductivity

DISTRIBUTARY CHANNEL SITES



CONNECTED LAKE SITES



PERCHED LAKE SITES

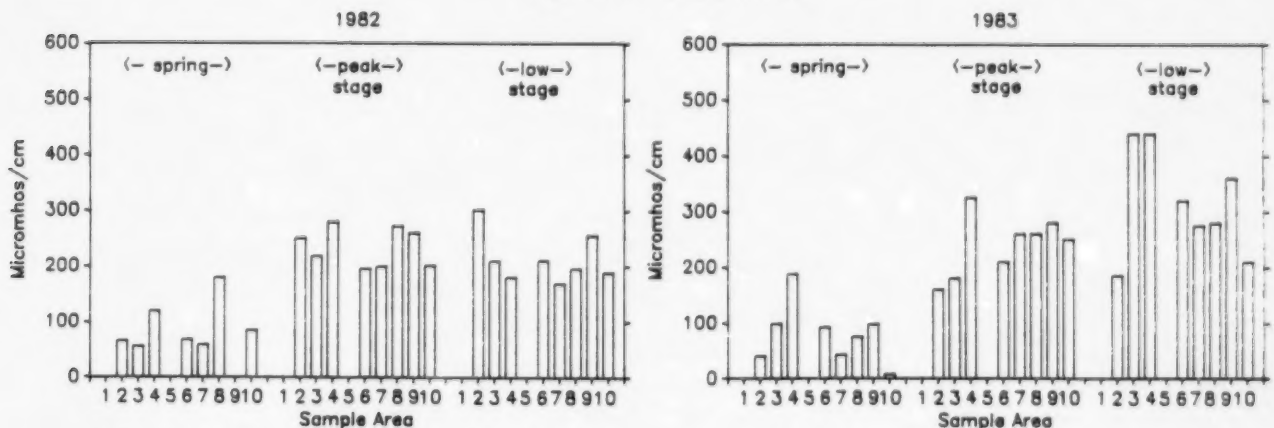


Figure 4: Conductivity, at 10 study Areas in the Mackenzie Delta, N.W.T., prior to spring break-up, and at peak and low stages.

measurements did not clearly define spatial trends. No significant spatial differences in the amount of dissolved solids contained in lake and channel waters was detected at the time of sampling. There was, however, a slight tendency for lakes and channels located in the southern and central Delta to have higher conductivity values than those located in the northern portion, regardless of the time of year. Also, variations among lake sites were more pronounced than among distributary channels, particularly in 1983 (Figure 4).

Temporally conductivity was a much more useful indicator. A clockwise hysteresis relationship, similar to the type described by Whitfield and Schreier (1981) and Johnson and East (1982) was inferred between water level and conductivity. Prior to spring flooding, conductivity of ice core samples was very low. Flooding caused water levels to rise and the conductivity of samples taken during this period showed a marked increase from spring values. By late summer, water levels were much lower, but conductivity reading for water samples collected during this period were much higher than those recorded during the spring flood. This phenomenon was most prevalent at lake sites (Figure 4).

3.3c pH

The pH level is an important factor in the quality of the aquatic environment. pH was measured at each of the Delta study sites over the two year study period, prior to break-up, and during peak and at low water level periods. Discharge during peak and low water level periods is not expected to effect the pH levels.

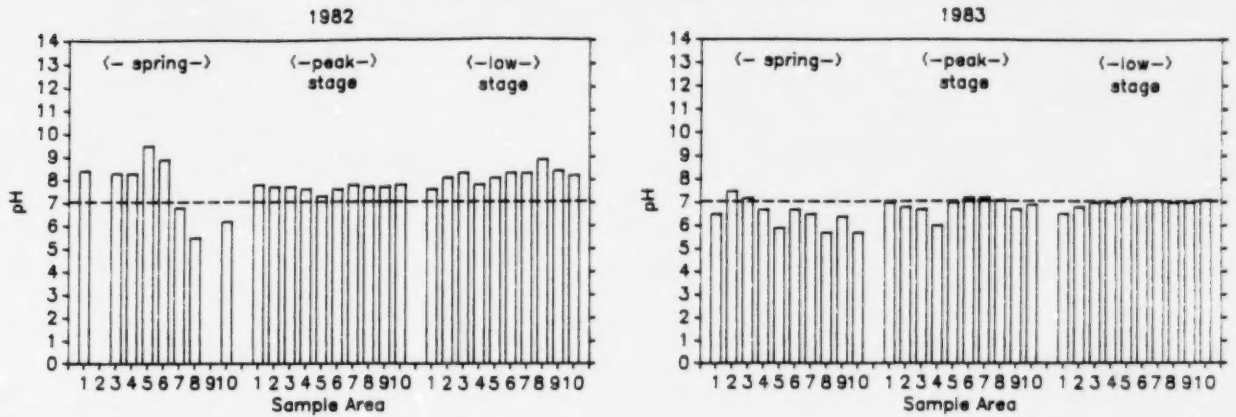
Distributary channels had a pH range between 5.5 and 9.5, with an average pH of 7.2 over the study period. For the most part, ice cores obtained from the channels were slightly basic. Once the Delta was flooded, and after during the open water season, the pH levels averaged 7.0 (Figure 5).

The pH range for connected lakes was between 5.7 and 8.9, with an average pH value of 7.1. The pH of spring samples were slightly acidic with an average of 6.8. Water samples taken during the spring flood and later during the open water season at these lake sites had an average pH of 7.2.

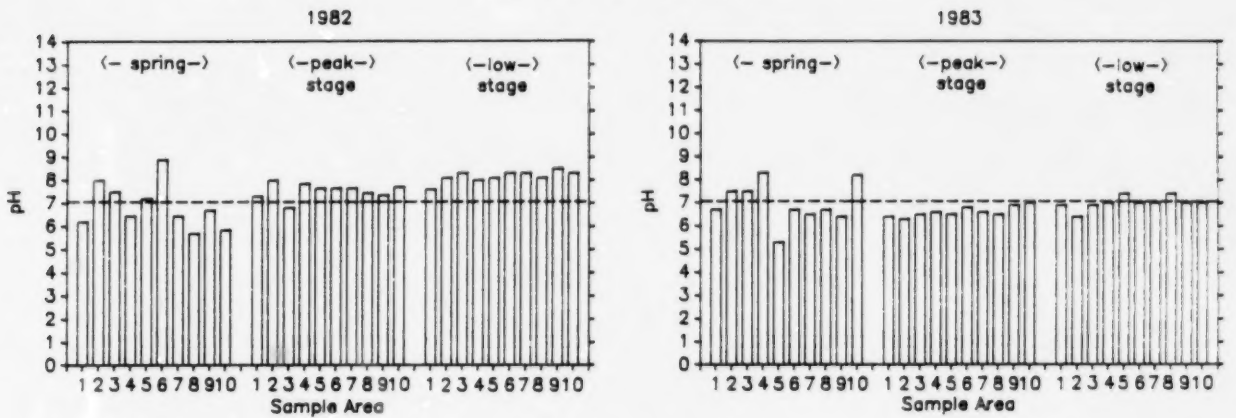
Perched lakes had a pH range of 5.1 to 9.8, with an average of 7.5. The pH of ice core samples taken in the spring from these lakes varied among sites, but were usually below 7.0. With the advent of spring flooding and higher water levels, the pH readings of water samples taken from perched lakes tended to be neutral. This was also observed for samples taken late in the season, when water levels in these lakes were much lower (Figure 5).

Except for a few outliers, pH levels measured at Delta lake and channel study sites were well within the suggested limits (6.5 to 9.0 ; Environment Canada, 1979) set for the protection of the aquatic environment. These outliers may be the result of sampling which cannot always be controlled and which may change the pH of water, or the carbon dioxide-bicarbonate-carbonate equilibrium which is easily disturbed and can also change the pH of natural water (Hem, 1970). Data showed that discharge during peak and low water level periods did not affect pH levels.

DISTRIBUTARY CHANNEL SITES



CONNECTED LAKE SITES



PERCHED LAKE SITES

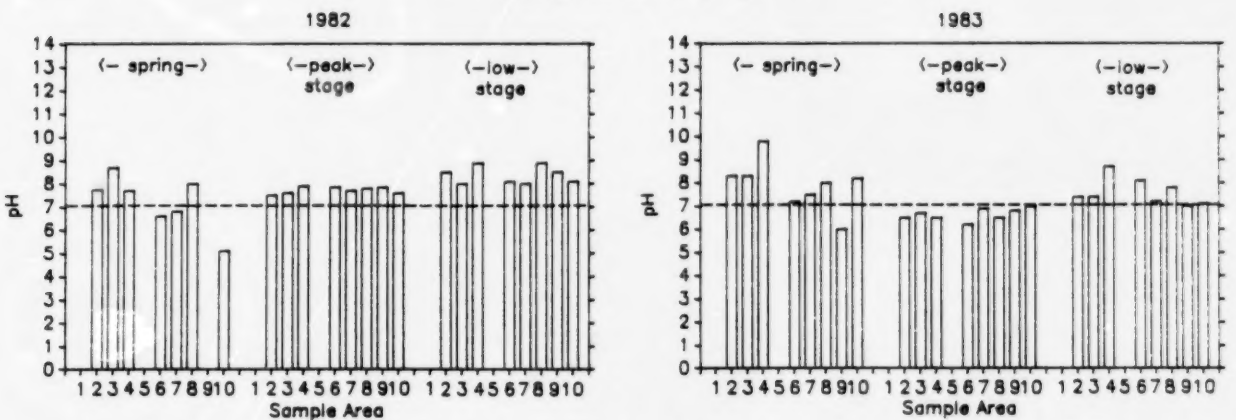


Figure 5: pH, at 10 study Areas in the Mackenzie Delta, N.W.T., prior to spring break-up, and at peak and low stages.

Distributary channels had a marked spatial trend in the samples collected during the spring. Basic pH levels were recorded at southern Delta sites and slightly acidic levels were recorded at northern sites. Overall, pH levels varied a great deal among distributary channel sites during the high water year (1982), when compared to a "normal" water year, which was the case in 1983 when pH levels among channel sites were quite similar (Figure 5).

Connected lakes mirrored the spatial and temporal pH trends of their respective distributary channels. There was, however, less variation in pH levels among lakes sites than distributary channel sites during peak and low water level periods. The pH levels were slightly more basic during the high water year (1982) than those measured during the 1983 season.

The pH levels observed for perched lakes were generally more basic and varied a great deal more among lake sites over the field season (Figure 5). Part of the variations in pH observed from site to site was due to the fact that these lakes are normally isolated from the other lakes and channels in the Delta, except during the spring flood or occasionally during high water.

3.3d TURBIDITY

Turbidity is very sensitive to seasonal changes in the hydrologic regime. As such, the time of sampling has a direct bearing on observed turbidity values. The closer the period of sampling is to peak stage, the greater the expected turbidity. In 1982, water samples were taken several days prior to the peak stage, whereas those taken in 1983 were collected several days after peak stage (Table 1). This may be one reason for the lower turbidity levels recorded for 1982. Unfortunately this sequence of events has biased the data somewhat, but

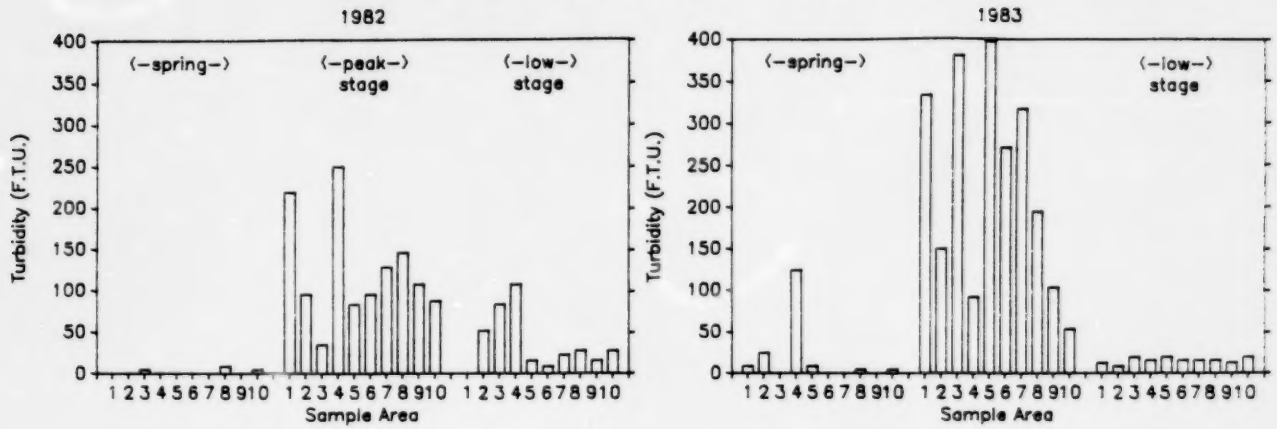
is nevertheless useful and shows some interesting patterns (Figure 6).

Ice core samples from distributary channels had very low turbidity readings as most of the solid materials in suspension had settled out prior to freeze-up. The average turbidity reading for distributary channel ice core samples was 9.8 FTU. With the advent of spring flooding in the Delta, turbidity levels varied a great deal from site to site. Turbidity measurements ranged from 400 to 54 FTU, with an average value of 177 FTU. By late summer, much of the material in suspension had settled out and turbidity was much lower, with an average of 26 FTU. Spatially turbidity varied a great deal among the channel sites, but there were no detectable trends (Figure 6).

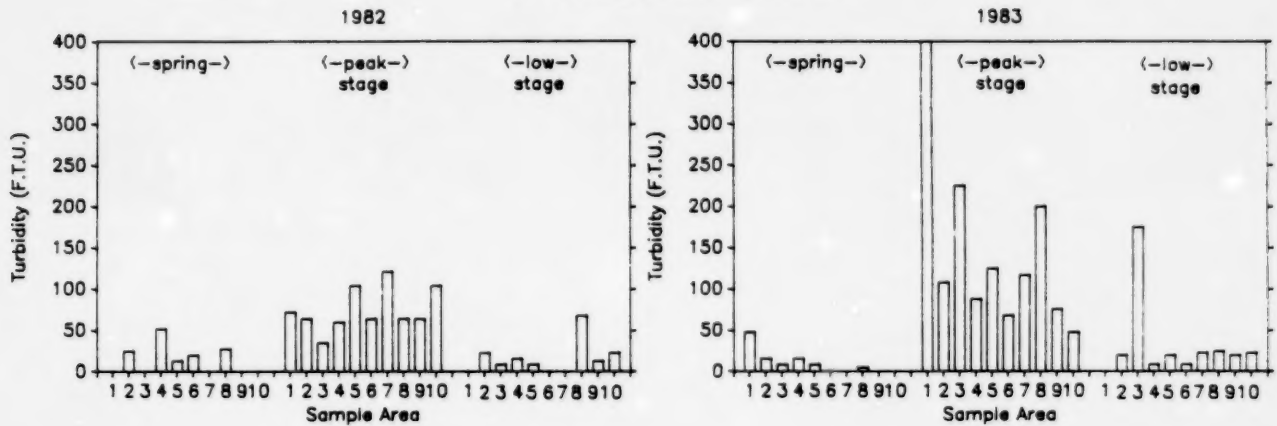
In the spring most connected lakes are still frozen solid to the lake bed. Consequently, ice core samples taken during this period contained very little suspended material. The average turbidity reading for these lakes was 12 FTU. Water samples taken during the spring flood period, showed that turbidity levels varied greatly among sites with a range of 35 to 400 FTU, and an average of 110 FTU. Samples taken late in the summer had much lower turbidity with an average 24 FTU. Connected lakes, because of their low water connection to Delta channels, had similar temporal fluctuations in turbidity levels as their respective distributary channels. Here too, erratic variations in turbidity levels from site to site made it impossible to detect any spatial patterns.

Unlike the connected lakes, most of the perched lakes sampled do not freeze to the lake bed during the winter. In spite of this, the average turbidity

DISTRIBUTARY CHANNEL SITES



CONNECTED LAKE SITES



PERCHED LAKE SITES

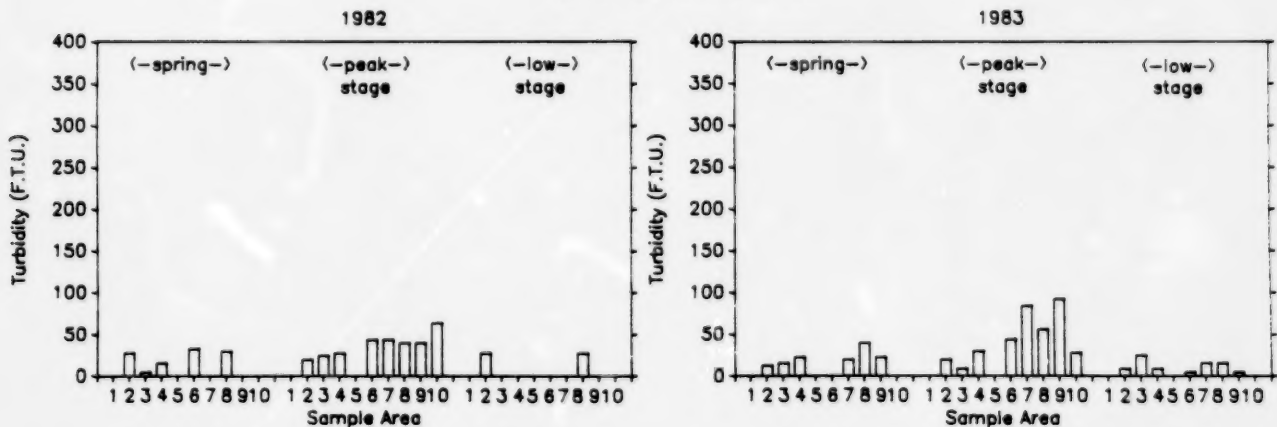


Figure 6: Turbidity, at 10 study Areas in the Mackenzie Delta, N.W.T., prior to spring break-up, and at peak and low stages.

reading was still low at 16 FTU, for ice core samples collected during the spring.

In 1982 the majority of perched lakes were flooded, a fact which is not truly reflected in the turbidity readings. On the other hand many of the perched lakes in the southern Delta were not flooded in 1983 whereas those located in the central and northern Delta were. Due to the time of sampling (i.e. just after the peak stage in 1983), a distinct spatial trend arises in the turbidity levels of perched lakes situated in the north-central and northern Delta (28 to 92 FTU) when compared to those in the southern and south-central Delta (9 to 30 FTU). Perched lakes also differed considerably from other Delta sites (i.e. distributary channels and connected lakes) in that the high turbidity levels measured at the other lake and channel sites were not found for perched lakes (Figure 6). The average spring turbidity reading was 35 FTU.

After the spring flood, water levels drop below the lake closure levels in all three regions of the Delta. Suspended material in these lakes settle out over the summer, resulting in a dramatic decrease in turbidity (Figure 6), with an average reading of only 7 FTU.

3.3e MAJOR IONS

As part of the alkaline-earth metal group, calcium is mostly derived from weathering of calcium-bearing nonsilicate minerals, especially the carbonates, such as sandstones and limestones. These two sedimentary rock types abound throughout the Mackenzie River basin (Geological Survey of Canada, 1970). Calcium is also one of the main components which make up total hardness, the

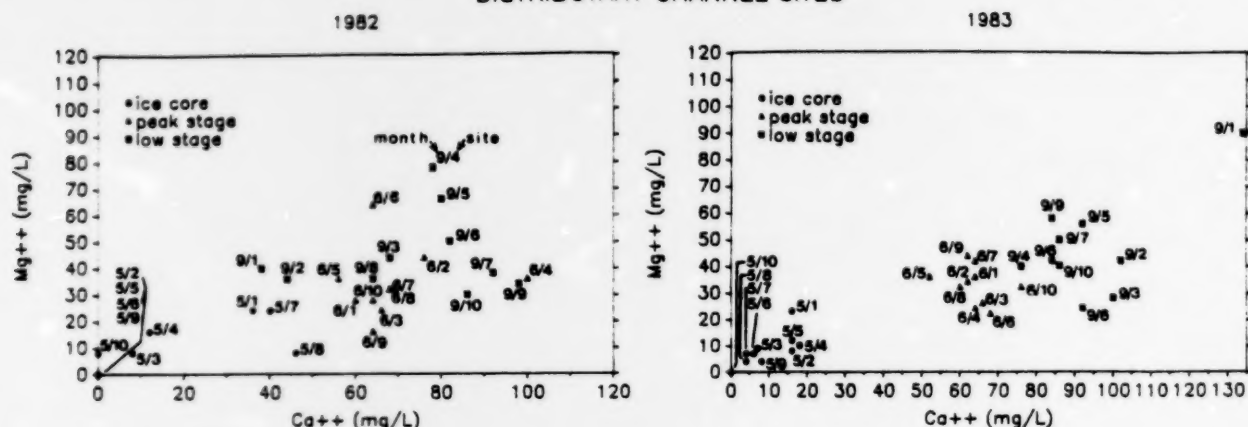
other being magnesium. Magnesium is also an alkaline-earth metal and is an abundant element in natural waters. It too is highly soluble and is present in dolomitic sedimentary rocks such as limestones and dolomites.

Ice core samples collected at distributary channel sites generally had a 2:1 calcium to magnesium ratio (Figure 7). The average calcium concentration was 12 mg/L with magnesium at 9 mg/L. During peak stage, calcium and magnesium concentration increased sharply, averaging 66 mg/L and 33 mg/L respectively. Calcium had a range of 50 to 100 mg/L, and magnesium fell between 16 and 64 mg/L. Low water levels in the autumn saw these same channel sites increase their Ca-Mg concentrations by an average of 20 mg/L each. Calcium and magnesium concentrations fluctuated a great deal from site to site, making it impossible to establish any type of spatial trend. Channels also showed a great range in the Ca-Mg ratios (Figure 7).

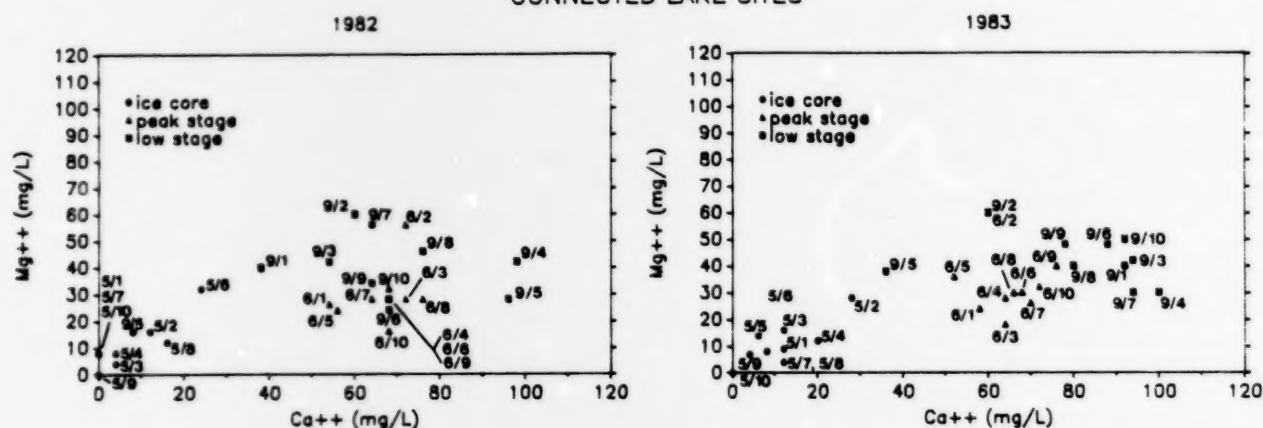
Calcium and magnesium concentrations averaged 9 mg/L and 11 mg/L respectively in ice cores collected at connected lake sites. Many of the lake sites had higher concentrations of magnesium than calcium, sometimes as much as two to one. Once break-up and flooding commence, a reversal in the dominant cation occurs, with an increase in calcium concentrations of three to fourfold at all lake sites. The average calcium content was 66 mg/L, and the average magnesium content was 30 mg/L. A 2:1 Ca-Mg ratio was maintained for the remainder of the field season. No spatial trends could be detected, as concentrations varied considerably among lake sites (Figure 7).

Spring concentrations of calcium and magnesium in ice core samples taken at perched lake sites averaged 10 mg/L and 12 mg/L respectively. Once again

DISTRIBUTARY CHANNEL SITES



CONNECTED LAKE SITES



PERCHED LAKE SITES

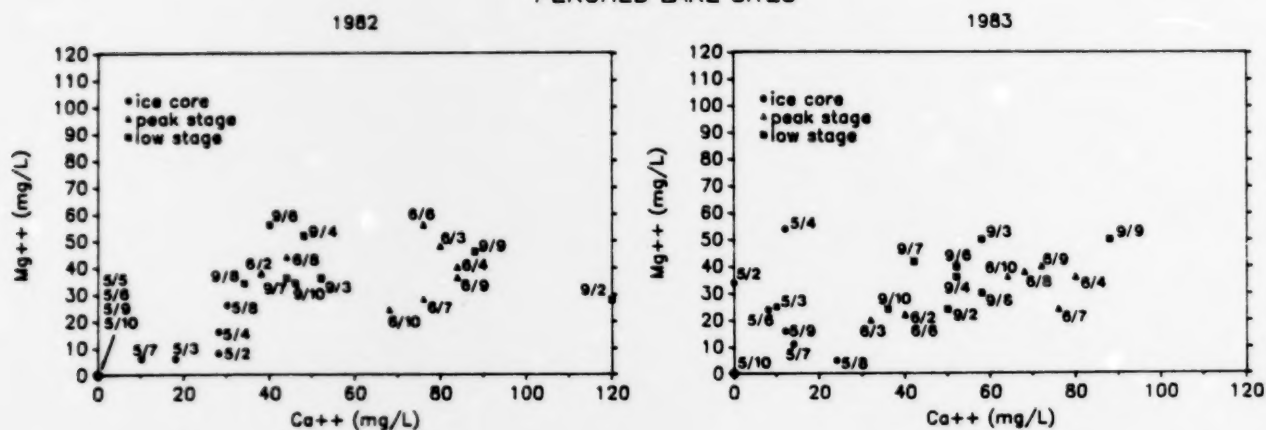


Figure 7: Calcium and Magnesium Concentrations, at 10 study Areas in the Mackenzie Delta, N.W.T., prior to spring break-up, and at peak and low stages.

magnesium was the dominant cation until flooding occurred in the spring. The reversal saw calcium concentrations increase by 20 to 65 mg/L, with an average value of 50 mg/L. Magnesium had an average concentration of 28 mg/L. Calcium and magnesium concentrations were quite varied among sites, making it impossible to establish any sort of spatial trend (Figure 7).

In general, Delta lake and channel water can be considered moderately soft (total hardness <120 mg/L), according to the guidelines established by Environment Canada (1979). Temporally and spatially, calcium is the dominant cation found in the waters of lakes and channels in the Mackenzie Delta.

The prevalence of a higher magnesium to calcium ratio at many of the study sites in the spring may be due to sea-water contamination, which has an approximate calcium to magnesium ratio of 1:5 (Hem, 1970). Prior to freeze-up in October, the dominant winds are from the northwest bringing magnesium rich precipitation originating off the Beaufort Sea coast. Once spring mobilization of sediments begins in the Mackenzie basin, the calcium to magnesium ratio is roughly 2:1. Still, this low value may be an indication that precipitation originating off the coast is still a possible contaminant during the open water period. However, there was a strong temporal trend in calcium and magnesium concentrations at all the study sites which was inversely related to water level.

4.0 CONCLUSIONS

The preceding analysis, and the conclusions are based upon periodic single water samples which have limitations when used to describe trends in water quality characteristics over an extended period of time (Oguss and Erlebach, 1976). More frequent visits to the study areas would have been preferable, but manpower constraints and monitoring funds were not sufficient to mount an intensive study. However, due to the paucity of information on the water quality characteristics of lakes and channels in the Mackenzie Delta, temporal and spatial interpretations of the data collected during the 1982 and 1983 field seasons are offered, and whenever possible an effort is made to advance plausible explanations for the variations in the water quality of Delta lakes and channels.

Lake and channel water quality characteristics showed strong seasonal fluctuations in water temperature, conductivity, pH, turbidity and ionic concentrations of calcium and magnesium in response to variations in the water level.

Prior to break-up, ice core samples showed conductivity, pH, turbidity and ionic concentrations of calcium and magnesium to be quite low. Snow samples analyzed from lake catchments in Areas 2, 4 and 8 (Table 2) had very low ionic strength. As a result, snowmelt runoff acts as a dilutant rather than a "signature" input to the surrounding lakes and channels.

At the onset of spring break-up in the headwater region of the Mackenzie River, high flows and ice erosion mobilize suspended material. By the time break-up and flooding occur in the Delta, the water entering the channel system is warm and sediment-laden. As a result, measurable increases in water temperature, conductivity, turbidity, and calcium-magnesium concentrations were encountered during the spring sampling period.

There was little spatial variation observed in water samples collected during the open water period. What spatial variations there were in the water chemistry of lakes and channels was attributed to the morphological characteristics of the three Delta regions. These regions also play an important role in controlling the water level of Delta lakes and channels. Connected lakes have a water filled distributary channel linking them to main Delta channels. This allows for a constant exchange of water between channels and connected lakes in the Delta. As a result, a wide range of values in water quality characteristics is displayed at these study sites throughout the field season. Perched lakes on the other hand, depending on their location in the Delta, can be unconnected or have a low-closure or a high-closure, which regulates the lake water inflow and outflow. This flow regulation has a direct bearing on the lake water chemistry. Once the spring flood has subsided, these lakes have a stable hydrologic environment, allowing more time for the deposition of suspended material, and the dilution of inputs (i.e. dissolved constituents). Consequently, perched lakes have a much smaller range in water temperature, conductivity, pH, turbidity, and ionic concentrations of calcium and magnesium when compared to connected lakes and distributary channels for the same period.

This study underlines the importance of spring break-up and flooding to the chemical composition of Delta lake and channel waters. Much of the replenishment of minerals required to sustain plant and animal populations in the Delta occurs during the spring flood period. It has also shown that if the time of sampling coincides with extreme events in the hydrological regime, temporal variations in the water quality characteristics of Delta lakes and channels are readily measurable. On the other hand it has demonstrated that spatial variations in the water quality characteristics of Delta lakes and channels are not as easy to detect, and require a much more intensive sampling period than was used in this study.

In order to develop an understanding of the natural and anthropogenic changes occurring in the chemical composition of Delta lake and channel water, much more money, time and effort will have to be expended on water quality monitoring and analysis in the Mackenzie Delta. With this type of information, the Mackenzie Delta may be spared some of the serious ecological changes which often accompany socio-economic development of a region.

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TABLE 1

LAKE VOLUMES AT TIME OF SAMPLING

AREA 2, MACKENZIE DELTA
UNCONNECTED LAKE

EVENT	DATE	WATER LEVEL (m. asl)	LAKE VOLUME (m ³)
SAMPLE	16/05/82	7.64	2240
SAMPLE	25/05/82	7.64	2240
PEAK STAGE	03/06/82	9.31	19311
SAMPLE	11/08/82	9.01	16244
AVERAGE		8.80	14098
SAMPLE	03/05/83	9.05	16653
PEAK STAGE	01/06/83	9.05	16653
SAMPLE	11/06/83	9.05	16653
SAMPLE	21/08/83	8.76	13689
AVERAGE		8.91	15222

AREA 2, MACKENZIE DELTA
CONNECTED LAKE

EVENT	DATE	WATER LEVEL (m. asl)	LAKE VOLUME (m ³)
SAMPLE	07/05/82	6.74	100302
SAMPLE	25/05/82	6.76	101919
PEAK STAGE	01/06/82	9.58	330026
SAMPLE	11/08/82	6.88	111626
AVERAGE		7.34	148835
SAMPLE	03/05/83	6.65	93022
PEAK STAGE	04/06/83	8.41	235386
SAMPLE	11/06/83	8.14	213546
SAMPLE	21/08/83	6.65	93022
AVERAGE		6.87	110817

TABLE 1 (Cont.)
LAKE VOLUMES AT TIME OF SAMPLING

AREA 4, MACKENZIE DELTA
HIGH-CLOSURE LAKE

EVENT	DATE	WATER LEVEL (m. asl)	LAKE VOLUME (m ³)
SAMPLE	03/05/83	3.83	58602
PEAK STAGE	06/06/83	6.30	189191
SAMPLE	11/06/83	4.09	72348
SAMPLE	21/08/83	3.63	48028
AVERAGE		3.86	60188

AREA 4, MACKENZIE DELTA
CONNECTED LAKE

EVENT	DATE	WATER LEVEL (m. asl)	LAKE VOLUME (m ³)
SAMPLE	03/05/83	1.59	1740051
PEAK STAGE	06/06/83	5.85	7866182
SAMPLE	11/06/83	4.72	6241175
SAMPLE	21/08/83	1.43	1509961
AVERAGE		2.89	3609527

TABLE 1 (Cont.)
LAKE VOLUMES AT TIME OF SAMPLING

AREA 8, MACKENZIE DELTA
LOW-CLOSURE LAKE

EVENT	DATE	WATER LEVEL (m. asl)	LAKE VOLUME (m ³)
SAMPLE	07/05/82	1.73	27722
SAMPLE	25/05/82	2.61	50104
PEAK STAGE	02/06/82	4.97	110128
SAMPLE	11/08/82	1.75	28231
AVERAGE		2.34	43237
SAMPLE	03/05/83	1.57	23653
PEAK STAGE	05/06/83	4.34	94105
SAMPLE	11/06/83	2.36	43746
SAMPLE	21/08/83	1.75	28231
AVERAGE		1.89	31792

AREA 8, MACKENZIE DELTA
CONNECTED LAKE

EVENT	DATE	WATER LEVEL (m. asl)	LAKE VOLUME (m ³)
SAMPLE	07/05/82	1.02	2094972
SAMPLE	25/05/82	1.70	3057527
PEAK STAGE	03/06/82	4.50	7020988
SAMPLE	11/08/82	0.46	1302279
AVERAGE		1.22	2378076
SAMPLE	03/05/83	0.30	1075796
PEAK STAGE	07/06/83	3.74	5945192
SAMPLE	11/06/83	2.16	3708667
SAMPLE	21/08/83	0.22	962554
AVERAGE		0.48	1330590

TABLE 2

WATER QUALITY CHARACTERISTICS OF SNOW AND ICE SAMPLES

AREA 2	ICE		SNOW
	WHITE	BLACK	
Conductivity $\mu\text{S}/\text{cm}$	150	82	14
pH	8.2	7.5	6.3
Turbidity (FTU)	60	108	0
Calcium mg/L	52	28	0
Magnesium mg/L	16	16	0
AREA 4	ICE		SNOW
	WHITE	BLACK	
Conductivity $\mu\text{S}/\text{cm}$	14	70	16
pH	6.4	7.4	6.2
Turbidity (FTU)	0	25	0
Calcium mg/L	0	12	0
Magnesium mg/L	0	20	0
AREA 8	ICE		SNOW
	WHITE	BLACK	
Conductivity $\mu\text{S}/\text{cm}$	26	200	12
pH	7.4	8.2	6.4
Turbidity (FTU)	16	60	0
Calcium mg/L	4	46	0
Magnesium mg/L	12	42	0